Effect of Oil Pollution on Compaction, Strength and Permeability Characteristics of Fly Ash-Sand Composite

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Abstract:- In this study, the variation of compaction, strength and permeability characteristics of fine sand-fly ash composite are studied with varying percentage of fly ash and contaminating oil product used was diesel. After compaction at maximum dry density with optimum water content, the load bearing characteristics, California bearing ratio (CBR), and permeability characteristics of fly ash-fine sand composite and the optimum sand: fly ash mix contaminated with diesel were evaluated. The compaction characteristics of fly ash-sand composite are improved and optimum value of maximum dry density is achieved for 32% fly ash content. The CBR values are observed to improve and the maximum values of soaked and un-soaked CBR are observed for the optimum fly ash content. The maximum dry density of diesel polluted soil composite decreases upon increasing the diesel content and the optimum moisture content also decreases. The un-soaked and soaked CBR values of the soil composite decrease as diesel content in the sand-fly ash composite increases. The permeability of soil composite decreased upon increasing the fly ash content. The permeability of composite decreases further upon contamination with increasing percentages of diesel. Thus, fly ash-fine sand composite can be used in construction of sub-grade for oil storage tanks.

Key-words: - Sand-fly ash, diesel, compaction, strength, permeability.

1. Introduction

The study of soil whether contaminated or uncontaminated has been carried out since long time, but much data related to soil contaminated with petroleum products is not available. From the starting i.e. refinery to-its-distribution at depot, some part of these petroleum product is leaked out to earth surface. When some construction works like underground tank on such soils is to be carried out it should be assured that these petroleum products are not mixed with ground water. For this purpose, first of all compaction and permeability properties of soil are studied and a lining material is used under the construction work. If this lining material is taken from waste products it will be economical as well as reduce the problem of disposal of that waste product. The growth in various types of industries together with population growth has resulted in enormous increase in production of various types of waste materials. Fly ash is one of the wastes produced by thermal power plants. The estimated fly ash wasted by thermal power plants is 150 million tonnes in India every year. Fly ash materials as a waste byproduct are produced during combustion of coal I by thermal power plants and present a serious ecological problem associated with their storage and disposal. Therefore, the development of suitable scientific, technical and economic solutions of fly ash utilization is very pressing and important. Because of the complex physical and mechanical properties with respect to low price and low density, fly ash can be an extremely attractive material applicable for the synthesis of composites. This very unique and inexpensive composite powder resource, unlike those synthetically produced in a favorable spherical form with wide ranges of size and density, may be suitable in various light weight structural applications. As such there is a growing need to recycle these waste materials for engineering applications. In this context, fly ash mixed with fine sand can be used for reduction in hydraulic conductivity against the contaminated soils and has effective role in protective controls. In India around 70% of power generated is from thermal power plants and produce large amount of waste product. One of such waste product got from the thermal power plant is fly ash. The efficacy of using fly ash mixed with fine sand as liner material for oil contaminated area and effect on the permeability of contaminated soil can be determined by conducting suitable laboratory tests. The utilization of a solid
waste such as fly ash can help in reducing the pollution of eco system of the region. The objective of the study is to evaluate and determine the effectiveness of fly ash as liner material for confinement of contaminated area and to assess the effect of permanent fluid such as oil on the geo-environmental properties of soils such as compaction, strength and permeability.

2. Scope and objectives
Physical characteristics of sand amended with fly ash were investigated by various researchers. Campbell et al (2000) conducted various laboratory tests on coarse sand fraction mixed with 0-100% of fly ash by weight and showed that the hydraulic conductivity of sand decreased remarkably with the addition of fly ash. Measured void ratios of mixes showed minimum value at 36% and 20% fly ash by volume for fine and coarse sand mixes. Significant efforts have been made in recent years to use fly ash in civil engineering construction. Mathur et al (2003, 2005) have used fly ash in embankment with the technique of reinforced earth with a view to use this waste in road work. Kaushik and Ramasamy (2006) examined the various properties of coal ash to be used as good construction material in geotechnical applications. It is observed that fly ash exhibits high strength at compaction moisture content but poor shear strength characteristics under saturated conditions. Kumar and Singh (2007) investigated the influence of various reinforced fly ash parameters through static and dynamic load tests and semi field test. They concluded that there is variation in the unconfined compressive strength of fly ash sub-bases with different reinforcement materials. Bhatta (2008) concluded that the addition of river sand to pond ash improved the CBR value so that it could be used for construction of sub grade. Chauhan et al (2008) observed that optimum moisture content increases and maximum dry density decreases with increased percentage of fly ash mixed with silty sand. Eskioglou and Oikonomou (2008) showed that the addition of ash increased the optimum moisture content in the compaction tests. The increase in optimum moisture content contributes to increase in the stabilization capacity of soil. Prasad (2011) studied behavior of reinforced fly ash sub-base for flexible pavement and showed that with increase in reinforcement, CBR value improved. Several research studies have been carried out to investigate the engineering characteristics of petroleum fuel contaminated soils. Al-Sanad et al (1995) and Al-Sanad and Ismail (1997) carried out laboratory tests to investigate the influence of oil contamination and aging effect on geotechnical properties of Kuwaiti sand. The results indicated a small reduction in strength and permeability and an increase in compressibility due to contamination. Aging reduced the oil content due to evaporation of volatile compounds and hence increased the strength and stiffness of the oil contaminated Kuwaiti sand specimens. Evgin and Das (1992) carried out a series of triaxial tests on contaminated and uncontaminated sands and found that the oil contaminated samples significantly decreased the friction angle for both loose and dense samples. Shin et al (1999) and Shin and Das (2001) indicated that the bearing capacity of footing decreased drastically with the increase of oil contamination. Khamehchiyan et al. (2007) studied the effect of crude oil on geotechnical properties of coastal soils and showed that the compactability of soil samples increased with increasing oil content leading to reduction of maximum dry density and optimum water content. Oil contamination induced a reduction in permeability and strength in the soil samples. Rahman et al (2010) concluded that oil-contaminated soils also indicated a lower maximum dry density (MDD) and optimum water content if compared with uncontaminated soils. A reduction in permeability was observed as a result of the oil contamination. This experimental investigation is carried out to study the effect of addition of fly ash and to fine sand on compaction, strength and permeability of the mix for use in construction of sub-grade. The compaction, strength and permeability characteristics of diesel-polluted fine sand-fly ash composite have been studied.

3. Engineering properties of materials used
3.1 Fly ash
Fly ash is produced as a waste by-product during combustion of coal in thermal power plants and presents serious ecological problem associated with its storage and disposal. The properties of fly ash are given in Table 1. The particle size distribution curve for fly ash is shown in figure 1.

3.2 Sand
Fine sand obtained from Beas river bed was used which can be classified as poorly graded sand (SP). The properties of sand are given in Table 2.

3.3 Oil pollutant
The oil used in this work is diesel normally used as fuel in motor vehicles. During refining, handling,
storage, transportation and use; oil gets spilt over the ground surface and may gradually percolate through pores and fissures and contaminate the soil and ground water. The diesel was used as contaminant in percentages of 4%, 9% and 13% in the experimental work.

Table 1: Properties of fly ash

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Chemical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.94</td>
</tr>
<tr>
<td>SiO₂</td>
<td>64.0%</td>
</tr>
<tr>
<td>Maximum dry density</td>
<td>11.81</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>24.0%</td>
</tr>
<tr>
<td>Optimum moisture content</td>
<td>33.0</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.8%</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>41.0</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.5%</td>
</tr>
<tr>
<td>MnO</td>
<td>0.03%</td>
</tr>
<tr>
<td>CaO</td>
<td>1.9%</td>
</tr>
<tr>
<td>MgO</td>
<td>1.5%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.2%</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.3%</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>1.77%</td>
</tr>
</tbody>
</table>

Table 2: Properties of sand

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.60</td>
</tr>
<tr>
<td>Maximum dry density</td>
<td>16.0</td>
</tr>
<tr>
<td>Optimum moisture content</td>
<td>6.0</td>
</tr>
<tr>
<td>Uniformity coefficient, Cₜ</td>
<td>2.11</td>
</tr>
<tr>
<td>Coefficient of curvature, Cₑ</td>
<td>1.315</td>
</tr>
</tbody>
</table>

4. Methodology

The particle size distribution tests were performed in accordance with IS: 2720-1975 (Part IV). The particle size distribution curves of sand and fly ash are shown in figure 1. The specific gravity tests, consistency limit test and standard Proctor tests were conducted as per IS: 2720 (Part III, Part V and Part VII respectively). California bearing ratio (CBR) tests were performed in accordance with IS: 2720 - 1979 (Part XVI). The permeability tests were conducted as per IS: 2720 - 1966 (Part XVII). The composites of sand and fly ash were obtained by blending 5%, 12%, 20%, 28%, 32%, 36% and 40% of fly ash with fine sand and standard Proctor tests were conducted on these mixes. Un-soaked and soaked California bearing ratio tests were conducted in the standard mould on the samples compacted statically at MDD and OMC. Surcharge weight of 50N was used during testing. A metal penetration plunger of diameter 50 mm and 100 mm long was used to penetrate the samples at a rate of 1.25 mm/minute using computer controlled CBR testing machine.
of 10% using variable head permeameter which suited for a wide range of permeability values. The permeability tests were also performed on the optimum sand-fly ash mix (sand:fly ash::68:32) after adding diesel in percentages of 5%, 9% and 13%.

5. Results and discussion
5.1 Compaction Characteristics

Figure 2 shows the dry density-moisture content relationship for fly ash. The maximum dry density of fly ash is 11.81 kN/m$^3$ and optimum moisture content is 33.0%. The maximum dry density of fly ash is too low to be used in the construction of sub-grades. The dry density-moisture content characteristics of fine sand are shown in figure 2.

![Fig. 3 Effect of fly ash content on MDD and OMC of sand-fly ash mix](image)

The maximum dry density of sand is 16.0 kN/m$^3$ and optimum moisture content is 6.0%. The maximum dry density of fine sand is low and hence it cannot be effectively used in the construction of embankments for the roads and other purposes. The compaction characteristics of fine sand and fly ash mixes for fly ash content of 5%, 12%, 20%, 28%, 32%, 36% and 40% are shown in figure 2. The maximum dry density values of fine sand-fly ash mixes increase from 16.0 kN/m$^3$ to 17.15 kN/m$^3$ for fly ash content increasing from 0 to 32% and then decreased to 16.05 kN/m$^3$ for fly ash content increases up to 40%. The optimum moisture content values increase from 6.0% to 28.0% for the fly ash content increasing from 0 to 40% in the composite. Thus, it is observed that the addition of fly ash to fine sand yields a composite with improved maximum dry density. This soil composite can be effectively used in the construction of sub-grades and embankments. Figure 3 shows the variation of maximum dry density with the addition of fly ash in the sand-fly ash composite. It is observed that with the addition of fly ash, the maximum dry density increases nonlinearly up to 32% fly ash content and afterwards it decreases with increase in fly ash content.

The variation of optimum moisture content with addition of fly ash in sand-fly ash composite is shown in figure 3. With the addition of increasing percentage of fly ash, the optimum moisture content increases nonlinearly. The addition of fly ash to fine sand increases the maximum dry density of the mix due to the infilling of voids in uniformly graded fine sand up to an optimum percentage of fly ash and thereafter the maximum dry density decreases due to extra content of fly ash which cannot be accommodated in the voids in sand mass. Fly ash particles being very fine in nature, the optimum moisture content of the composite increases with increase in fly ash content due to more water required for lubricating the particles.

![Fig. 4 Effect of diesel content on MDD and OMC of sand-fly ash mix](image)

Figure 4 shows the variation of maximum dry density with the addition of diesel in the sand-fly
ash composite. Upon adding diesel contaminant, the maximum dry density decreases nonlinearly as the diesel content increases. The maximum dry density value of diesel contaminated fine sand-fly ash (68: 32) mixes decreased from 17.15 kN/m$^3$ to 15.80 kN/m$^3$ for the diesel content increases from up to 13%.

The variation of optimum moisture content with addition of diesel in sand-fly ash composite is shown in figure 4. It is observed that with the addition of increasing percentage of diesel, the optimum moisture content decreases. The optimum moisture content value of diesel contaminated fine sand-fly ash (68: 32) mixes decreases from 24% to 18.75% for the diesel content increasing from up to 13%.

5.2 California Bearing Ratio tests Results

Figure 5 shows the variation of unsoaked and soaked California bearing ratio with percentage of fly ash in the soil composite. The un-soaked CBR value of the soil composite increases from 10.8% to 18.4% as the percentage of fly ash increases from 0 to 32% and then decreases to 12.9% as fly ash content increases further to 40%.

Soaked CBR values of the mix increase from 6.4% to 9.8% as the percentage of fly ash increases from 0 to 32% and then decreases to 6.9% with fly ash content increasing up to 40%. The optimum CBR value of soil composite is obtained for a fly ash content of 32%.

The variation of unsoaked and soaked California bearing ratio with diesel content in the sand-fly ash composite (68: 32) is shown in figure 6. The un-soaked CBR value of the soil composite decreases from 18.8% to 16.9% as the percentage of diesel increases from 0 to 13%. Further, the CBR value of diesel polluted sand-fly ash composite under soaked condition decreases from 9.8% to 8.8% with increase in diesel content from 0 to 13%. This composite of sand-fly ash (68: 32) may be effectively utilized in the construction of sub-grades for the oil storage tanks or other purposes.

5.3 Permeability characteristics

The variation of permeability of the sand-fly ash composite with fly ash content varying from 0 to 70% is shown in figure 7. It is observed that the permeability of the soil composite decreases with increase in fly ash content nearly asymptotically. However at a fly ash content of 32%, the permeability is $3.42 \times 10^{-4}$ cm/sec which may be considered to be adequate for the sub-grades. Thus, sand-fly ash composite (68:32) possesses a maximum dry density of 17.15 kN/m$^3$, soaked CBR of 9.8% and permeability of $3.42 \times 10^{-4}$ cm/sec hence may be effectively utilized in the construction of sub-grades.
Figure 8 shows the variation of permeability of the sand-fly ash composite (68:32) with diesel contaminant percentages of 5%, 9% and 13%. The permeability of the contaminated soil composite decreases with the increase in diesel contaminant content to $0.98 \times 10^{-4}$ cm/sec for 5% diesel content and to $0.50 \times 10^{-4}$ cm/sec for 13% diesel content from $3.42 \times 10^{-4}$ cm/sec for the non-contaminated soil composite. The low permeability does not allow the spilled oil to contaminate the groundwater and thus the composite can be used as a sub-grade construction.

6. Conclusions

The spillage of oil during refining, handling, storage and distribution may percolate into the ground thereby polluting the soil. The oil storage tanks require good bearing strata without any differential settlements and the soil should have preferably low permeability. The sand-fly ash composite possesses improved load bearing characteristics as revealed by the California bearing ratio test results and permeability of diesel polluted composite is low and thus can be used in construction of embankments and sub-grades under the oil storage tanks. The following conclusions can be drawn from the study conducted on the sand-fly ash soil composite:

1. The maximum dry density of fine sand is low and hence it cannot be effectively used in the construction of embankments and sub-grades under the oil storage tanks or for other purposes. The maximum dry density of fly ash is very low for use in the construction of sub-grades.

2. The maximum dry density values of fine sand-fly ash mixes increase with fly ash content increasing from 0 to 32% and then decrease upon further increasing the fly ash content. The variation in the maximum dry density with increasing fly ash content in sand-fly ash composite is nonlinear. With the addition of increasing percentage of fly ash in the composite, the optimum moisture content increases nonlinearly.

3. The addition of fly ash to fine sand yields a composite with improved maximum dry density and the mix (sand: fly ash :: 68:32) having optimum value of maximum dry density can be utilized for construction purposes. Upon adding diesel contaminant, the maximum dry density decreases nonlinearly as the diesel content increases. It is observed that with the addition of increasing percentage of diesel, the optimum moisture content decreases.

4. The un-soaked and soaked CBR values of the soil composite increase when fly ash content increases from up to 32% and then decrease upon further increasing the fly ash content. The optimum CBR value of the soil composite is obtained for the fly ash content of 32%. The un-soaked and soaked CBR values of the soil composite decrease as the percentage of diesel content increases.
in the sand-fly ash composite (68: 32) increases.
5. With increase in fly ash content in the soil composite, the permeability decreases because fly ash forms a cementitious compound with fine sand which restricts the flow of water through the soil pores. The permeability of diesel polluted soil composite decreases with the increase in diesel content as compared to that for the non-polluted soil composite.
6. From these test results, an optimized mix of sand-fly ash composite (sand: fly ash: = 68: 32) having sufficient maximum dry density, comparatively better load bearing characteristics and less permeability may be obtained which can be effectively used in the construction of embankments, soil sub-grade and foundation bases for oil storage tanks or rural roads with lesser traffic volume.

References
2. Al-Sanad HA and Ismael NF, Aging effects on oil-contaminated Kuwaiti sand, J Geotechn and Geoeniv Eng, ASCE. 123(3), 1997, 290-293.